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1,2-DIBENZYL AND -DIARYLTETRADIMETHYLAMIDO-DIMOLYBDENUM AND -DI--ETC(U)

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1,2-DIBENZYL AND -DIARYLTETRADIMETHYLAMIDO-DIMOLYBDENUM

AND -DITUNGSTEN COMPOUNDS:  $M_2R_2(NMe_2)_4$  ( $M \equiv M$ ).

STRUCTURAL EFFECTS OF  $Me_2N$ -to-M  $\pi$ -BONDING.

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) From the reactions between $RMgCl$ ( $R = CH_2C_6H_5$ and $CH_2$ -p-tolyl) or $LiR$ ( $R = C_6H_5$ , p- and o-tolyl) (2 equiv) and $1,2-M_2R_2(NMe_2)_4$ compounds in hydrocarbon solvents, the new compounds $1,2-M_2R_2(NMe_2)_4$ ( $M \equiv M$ ), where $M = Mo$ and $W$ , have been isolated and characterized by a variety of physico-chemical techniques. The new compounds which are air-sensitive, hydrocarbon soluble and diamagnetic, are		

related to the "ethane-like" dimers previously characterized for R alkyl. The compound  $1,2\text{-Mo}_2(\text{CH}_2\text{C}_6\text{H}_5)_2(\text{NMe}_2)_4$  crystallizes in the space group  $P2_1/a$  with  $a = 17.595(7) \text{ \AA}$ ,  $b = 16.038(6) \text{ \AA}$ ,  $c = 10.542(4) \text{ \AA}$ ,  $\beta = 122.11(2)^\circ$ , with  $Z = 4$ . Pertinent bond distances and bond angles (averaged) are  $\text{Mo-Mo} = 2.200(1) \text{ \AA}$ ,  $\text{Mo-N} = 1.95(1) \text{ \AA}$ ,  $\text{Mo-C} = 2.19(1) \text{ \AA}$ ,  $\text{Mo-Mo-N} = 104(1)^\circ$ ,  $\text{Mo-Mo-C} = 100(1)^\circ$ . The central  $\text{Mo}_2\text{N}_4\text{C}_2$  skeleton has virtual  $C_2$  symmetry (gauche rotamer). The benzyl ligand is  $\sigma$ -bonded, not  $\pi$ -bonded, as evidenced by equivalent  $\text{Mo---C}_\gamma$  distances =  $3.7 \text{ \AA}$ . The compound  $\text{Mo}_2(\text{p-tolyl})_2(\text{NMe}_2)_4$  crystallizes in the anti-rotamer: the central  $\text{Mo}_2\text{N}_4\text{-C}_2$  unit has virtual  $C_{2h}$  symmetry. Crystal data are  $a = 8.046(2) \text{ \AA}$ ,  $b = 17.319(7) \text{ \AA}$ ,  $c = 18.179(8) \text{ \AA}$  with  $Z = 4$  in the space group  $Pcan$ . Pertinent bond distances and angles (averaged) are  $\text{Mo-Mo} = 2.196(1) \text{ \AA}$ ,  $\text{Mo-N} = 1.95(1) \text{ \AA}$ ,  $\text{Mo-C} = 2.156(4) \text{ \AA}$ ,  $\text{Mo-Mo-N} = 104(1)^\circ$ ,  $\text{Mo-Mo-C} = 101.6(1)^\circ$ . The compound  $1,2\text{-Mo}_2(\text{o-tolyl})_2(\text{NMe}_2)_4$  crystallizes in the gauche-rotamer and has crystallographically imposed  $C_2$  symmetry. Crystal data are  $a = 16.845(4) \text{ \AA}$ ,  $b = 17.651(5) \text{ \AA}$ ,  $c = 8.451(2) \text{ \AA}$ ,  $\beta = 102.74(1)^\circ$  with  $Z = 4$  and space group  $A2/a$ . Pertinent bond distances and angles are  $\text{Mo-Mo} = 2.226(1) \text{ \AA}$ ,  $\text{Mo-N} = 1.944(4) \text{ \AA}$ ,  $\text{Mo-C} = 2.169(4) \text{ \AA}$ ,  $\text{Mo-Mo-N} = 104(2)^\circ$ ,  $\text{Mo-Mo-C} = 105.0(1)^\circ$ . In all three compounds, the  $\text{Mo-NC}_2$  units are planar and the  $\text{NC}_2$  blades are aligned along the  $\text{Mo-Mo}$  axis leading to proximal and distal methyl groups. As a result of forming a  $\text{Mo}\equiv\text{Mo}$  bond, three  $\text{Mo-L}$   $\sigma$  bonds and two  $\text{Me}_2\text{N-to-Mo}$   $\pi$  bonds, each molybdenum attains a 16 valence shell electrons. The preferred alignment of the  $\text{NC}_2$  blades along the  $\text{Mo-Mo}$  axis is determined by the fact that only the in-plane d orbitals ( $d_{x^2-y^2}$ ,  $d_{xy}$ ) are available for ligand to metal  $\pi$ -bonding: the  $d_{z^2}$ ,  $d_{xz}$  and  $d_{yz}$  are used to form the  $\text{Mo}\equiv\text{Mo}$  bond. The  $\sigma$ -, rather than  $\pi$ -benzyl, ligand coordination reflects the importance of in-plane  $\text{Me}_2\text{N-to-Mo}$ -bonding as do the relatively high energy barriers observed in solution for rotation about  $\text{Mo-N}$  bonds,  $E_{\text{Act}} \text{ ca. } 14 \text{ Kcal mol}^{-1}$ . The lack of  $\pi$ -benzyl coordination along the  $\text{Mo-Mo}$  axis is also noteworthy and supports the previous suggestion that axial ligation to the  $(\text{M}\equiv\text{M})^{6+}$  unit is not favored. In  $\text{Mo}_2(\text{p-tolyl})_2(\text{NMe}_2)_4$ , the aryl ring is aligned along the  $\text{Mo-Mo}$  axis, but in solution rotation about the  $\text{Mo-C}$  bond is not frozen out even at  $-90^\circ\text{C}$ , 500 MHz. In  $\text{Mo}_2(\text{o-tolyl})_2(\text{NMe}_2)_4$ , the aryl ring is aligned perpendicular to the  $\text{Mo-Mo}$  axis and  $^1\text{H}$  nmr studies support the view that this conformation is also present in solution. These observations provide direct evidence for the importance of  $\text{Me}_2\text{N-to-M}$   $\pi$ -bonding which was previously invoked as a "stabilizing" influence for  $\beta$ -hydrogen containing alkyl compounds  $1,2\text{-M}_2\text{R}_2(\text{NMe}_2)_4$  ( $\text{M}\equiv\text{M}$ ) where  $\text{M} = \text{Mo}$  and  $\text{W}$ .

### Introduction

The field of organometallic chemistry has developed largely around soft and  $\pi$ -acceptor ligands such as CO, tertiary phosphines and  $\pi$ -olifins and polyenes. Hard  $\pi$ -donor ligands such as oxo, alkoxy and dialkylamido ligands have received little attention. In early transition metal chemistry, these ligands could be used to advantage in stabilizing metals in high oxidation states and low or unusual coordination numbers. Electronically these  $\pi$ -donor ligands offer functionality which may buffer changes in coordination number and electron count. They may act as terminal or bridging ligands and their  $\pi$ -electrons may occupy bonding or non-bonding molecular orbitals. The stabilization of unusual coordination numbers and geometries by  $\pi$ -donor ligands in the compounds  $\text{Mo}(\text{CO})_2(\text{O}-t\text{-Bu})_2(\text{py})_2$  and  $\text{Mo}(\text{CO})_2(\text{S}_2\text{CNR}_2)_2$  has attracted the attention of Hoffmann<sup>1</sup> and Templeton<sup>2</sup> and their coworkers. We have noted that RO- $\pi$ -donors may produce anomalous properties in other ligands which are coordinated to the same metal. For example, in  $\text{Mo}(\text{CO})_2(\text{O}-t\text{-Bu})_2(\text{py})_2$ ,<sup>3</sup> the carbonyl stretching frequencies are anomalously low for carbonyl groups bonded to Mo(2+),  $\nu(\text{CO}) = 1906$  and  $1776 \text{ cm}^{-1}$  and, in  $\text{Mo}(\text{O}-i\text{-Pr})_2(\text{bpy})_2$ ,<sup>4</sup> the 2,2'-bipyridine ligands appear partially reduced from X-ray and Raman studies. Qualitatively both of these observations may be rationalized in terms of RO-to-Mo  $\pi$ -bonding which enhances  $t_{2g}$ <sup>4</sup> backbonding to  $\pi^*$  acceptor ligands. We have also suggested that the isolation of thermally stable  $\beta$ -hydrogen containing alkyl compounds such as  $\text{M}_2\text{R}_2(\text{NMe}_2)_4$  ( $\text{M} \equiv \text{M}$ ) where  $\text{M} = \text{Mo}$  and  $\text{W}$ ,<sup>5</sup> and  $\text{TaR}(\text{NMe}_2)_4$ ,<sup>6</sup> where  $\text{R} = t\text{-Bu}$  and  $i\text{-Pr}$ , is possible because the  $\text{Me}_2\text{N}$ -ligands  $\pi$ -donate to metal atomic



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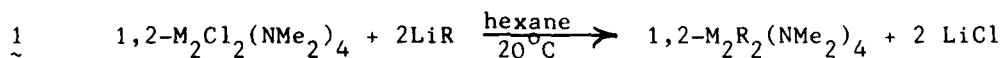
orbitals which would otherwise be available for mischevious M---H-C interactions. The  $\text{Me}_2\text{N}$  ligands suppress decomposition pathways that might involve an initial  $\beta$  (or  $\alpha, \gamma$ ) hydrogen abstraction. The generality of suppressing  $\alpha$ ,  $\beta$  or  $\gamma$  H abstraction remains to be established, but it should be noted that Schrock and his coworkers<sup>7</sup> have observed a similar effect. Specifically, complexes of the type  $\text{M}(\text{CHR})\text{L}_2\text{X}_3$  ( $\text{M} = \text{Nb}$  or  $\text{Ta}$ ,  $\text{R} = \text{CMe}_3$  or  $\text{Ph}$ ,  $\text{L} =$  a tertiary phosphine and  $\text{X} = \text{Cl}$  or  $\text{Br}$ ) react with terminal olefins to give organic products of  $\beta$ -hydride rearrangement of the four possible intermediate metallacyclobutane complexes (no metathesis products or cyclopropanes were observed), whereas with  $\text{M}(\text{CHCMe}_3)(\text{O}-t\text{-Bu})_2\text{Cl}(\text{PMe}_3)$  only metathesis products were obtained.

As part of a continuing study of the chemistry surrounding  $(\text{M} \equiv \text{M})^{6+}$  containing compounds ( $\text{M} = \text{Mo}$  and  $\text{W}$ ),<sup>8</sup> we have now prepared  $1,2\text{-M}_2\text{R}_2\text{-(NMe}_2)_4$  compounds where  $\text{R} =$  benzyl and aryl. The conformations and other structural aspects of these new compounds provide unequivocal evidence for the dominant role of  $\text{Me}_2\text{N-to-M } \pi$ -bonding in these types of complexes.

### Results and Discussion

Syntheses. The new compounds may be prepared by the general synthesis outlined in equation 1, for  $\text{R} = \text{CH}_2\text{C}_6\text{H}_5$ ,  $\text{CH}_2\text{-p-tolyl}$ , phenyl, o- and p-tolyl and  $\text{M} = \text{Mo}$  or  $\text{W}$ . An alternative synthesis using benzyl Grignard reagents has been used equally well for the synthesis of the benzyl compounds. The reactions proceed smoothly at room temperature and appear complete within two to three hours. Slow filtration using Celite and a fine frit yields hexane extracts which, upon reduction in volume of the solvent and cooling, give  $\text{M}_2\text{R}_2(\text{NMe}_2)_4$  as crystalline products in high

yields, ca. 70-80% based on eq. 1. Elemental analyses and other characterization data are given in Table I. The compounds are air-sensitive and must be handled in dry and oxygen-free atmospheres and solvents. They are more soluble in toluene and benzene than in hexane and alkane solvents. The general solubility trend for these compounds is  $R = \text{alkyl} > \text{benzyl} > o\text{- and } p\text{-tolyl} > \text{phenyl}$ . When heated in vacuo, these compounds sublime, but with decomposition. Purification by recrystallization is preferred to sublimation. In the mass spectrometer,  $M_2R_2(NMe_2)_4^+$  ions along with many other  $M_2$ -containing ions are observed.  $^1H$  nmr data and ir data are recorded in the experimental section.



#### Solid State and Molecular Structures

Gauche-1,2-Mo<sub>2</sub>(CH<sub>2</sub>Ph)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub>. An ORTEP view of the gauche-Mo<sub>2</sub>-(CH<sub>2</sub>Ph)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule found in the crystal is shown in Figure 1. The molecule has virtual, but not crystallographically imposed C<sub>2</sub> symmetry. Indeed, it is interesting to note that the Mo<sub>2</sub>(NC<sub>2</sub>)<sub>4</sub> skeleton has near perfect C<sub>2</sub> symmetry and it is only benzyl ligands which differ slightly with respect to each end of the molecule. This effect is clearly apparent from an inspection of the stereo views shown in Figure 2 in which the two halves of the molecule related by the virtual C<sub>2</sub> axis of symmetry are superimposed. A view of the molecule looking down the Mo-Mo axis is shown in Figure 3. This view shows how the planar Mo-NC<sub>2</sub> units are aligned coincident with the Mo-Mo axis; it also shows the orientation of the phenyl group with respect to the Mo-C bonds.

Final atomic positional parameters are given in Table II. Listings of bond distances and angles are given in Table III and IV, respectively. Many of these are expected in view of the previously characterized  $\text{Mo}_2\text{Me}_2(\text{NMe}_2)_4$ <sup>9</sup> and  $\text{Mo}_2\text{Et}_2(\text{NMe}_2)_4$ <sup>5</sup> compounds.

The Mo-C (benzyl) distance, 2.19(1) Å (averaged) is a perfectly respectable Mo-Csp<sup>3</sup> distance and may be compared with the related Mo-C (ethyl) distances of 2.165(6) Å and 2.21(1) Å (averaged) found in  $\text{Mo}_2\text{Et}_2(\text{NMe}_2)_4$ <sup>5</sup> and  $\text{Mo}_2\text{Et}_2(\text{NMe}_2)_2(\text{C}_7\text{H}_7\text{N}_3\text{C}_7\text{H}_7)_2$ <sup>10</sup>. Furthermore, the Mo-C-C angles, 104.5(4)° and 107.1(3)°, are close to idealized tetrahedral angles. That the benzyl ligand is σ-bonded ( $\eta^1$ ), rather than π-bonded ( $\eta^3$ ) is evident from the consideration of the following distances: Mo(1)-C(10), -C(11), -C(15) = 2.94(1), 3.71(1) and 3.63(1) Å, and Mo(2)-C(23), -C(24), -C(28) = 2.97(1), 3.69(1) and 3.76(1) Å, respectively. The two Mo---C(γ) distances for each Mo-benzyl group are roughly equal and at 3.7 Å, too long to allow for any π-allylic bonding. These distances may be compared to Mo-C(α) = 2.269(7) Å, Mo-C(β) = 2.364(5) Å, Mo-C(γ) = 2.480(6) Å and Mo---C(γ') (non-bonded) = 3.307(6) Å for the first structurally characterized  $\eta^5$ -benzyl-molybdenum complex,  $(\text{CH}_3\text{C}_6\text{H}_4\text{CH}_2)(\text{C}_5\text{H}_5)\text{Mo}(\text{CO})_2$ <sup>11</sup>. Qualitatively, the lack of any π-benzylic bonding or multicenter (aliphatic) C-H---Mo bonding in  $\text{Mo}_2(\text{CH}_2\text{Ph})_2(\text{NMe}_2)_4$  may be surmised by inspection of the view of the molecule shown in Figure 3.

Anti-1,2-Mo<sub>2</sub>(p-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>2</sub>. An ORTEP view of the anti-1,2-Mo<sub>2</sub>-(p-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule found in the solid state is shown in Figure 4. The molecule has virtual C<sub>2h</sub> symmetry and rigorous (crystallographically imposed) C<sub>2</sub> symmetry. The view shown in Figure 4 is down the C<sub>2</sub> axis of



symmetry. A view of the molecule looking down the Mo-Mo axis is shown in Figure 5. This view shows that the  $\text{NC}_2$  blades and the phenyl rings are aligned along the Mo-Mo axis.

Final atomic positional parameters are given in Table V and listings of bond distances and angles are given in Tables VI and VII.

The  $\text{Mo}\equiv\text{Mo}$ , Mo-N and M-C (tolyl) bond distances and the  $\text{Mo}_2\text{N}_4\text{C}_2$  angles are all entirely consistent with what one might have anticipated. The Mo-N( $\text{sp}^2$ ) distances are shorter than the Mo-C( $\text{sp}^2$ ) distances by 0.2 Å. It is safe to say that there is little, if any, Mo-tolyl  $\pi$ -bonding and so the markedly shorter Mo-N distance reflects the high degree of  $\text{Me}_2\text{N-to-Mo}$   $\pi$ -bonding. In the limit, this may be counted as a double bond,  $\text{M}=\text{NMe}_2$ .

Gauche-1,2-Mo<sub>2</sub>(o-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub>. In the space group A2/a, the gauche-1,2-Mo<sub>2</sub>(o-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule has crystallographically imposed C<sub>2</sub> symmetry. An ORTEP view of the molecule viewed down the C<sub>2</sub> axis is shown in Figure 6 and a view looking down the Mo-Mo axis is shown in Figure 7. Quite strikingly, the aryl plane is virtually perpendicular to the Mo-Mo-C plane. The aryl ring in the o-tolyl compound is rotated 90° from the alignment found for the p-tolyl ligand in 1,2-Mo<sub>2</sub>(p-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub>.

Final atomic positional parameters are given in Table VIII, and listings of bond distances and angles are given in Tables IX and X, respectively. The introduction of the more sterically demanding o-tolyl ligand causes certain systematic, though small changes in distances and angles from those associated with the p-tolyl compound. The Mo-Mo dis-

tance, 2.226(1) Å, is 0.03 Å longer; the Mo-C distance, 2.169(4) Å, is 0.01 Å longer. The Mo-Mo-C angle of 105.0° in the o-tolyl complex is larger than that in the p-tolyl complex (101.6°) while the N-Mo-N angle is correspondingly smaller, 115.7° (o-tolyl) compared to 120.2° (p-tolyl), as would be expected in order to accommodate the "sideways" or "perpendicular" conformation of the aromatic ring.

### <sup>1</sup>H nmr Studies

1,2-M<sub>2</sub>(benzyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> Compounds. In toluene-d<sub>8</sub> solutions, the M<sub>2</sub>-(benzyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> compounds show the presence of both anti and gauche rotamers with the gauche being preferred roughly 5:1. The methylene protons of the anti rotamer appear as a singlet while for the gauche rotamer they appear as an AB quartet which is consistent with expectations based on symmetry. Significantly, there appears to be free (unrestricted) rotation about Mo-C and C-C (phenyl) bonds on the nmr time scale which is in line with the view that the benzyl ligands are σ (not π) bonded. By contrast, rotations about Mo-N bonds are slow at low temperatures on the nmr time scale and at -45°C, 220 MHz, low temperature limiting <sup>1</sup>H nmr spectra are obtained which are consistent with frozen out proximal and distal N-methyl groups. At high temperatures, > 45°C, proximal ⇌ distal N-methyl exchange is fast on the <sup>1</sup>H nmr time scale, but anti ⇌ gauche isomerization is not. For compounds of the type 1,2-M<sub>2</sub>X<sub>2</sub>(NR<sub>2</sub>)<sub>4</sub>, where R = Me or Et and X = Me or CH<sub>2</sub>SiMe<sub>3</sub>, the latter process has been shown<sup>13</sup> to have an energy of activation of ca. 24 Kcal mol<sup>-1</sup>.

1,2-M<sub>2</sub>(aryl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> Compounds. The <sup>1</sup>H nmr spectra recorded in toluene-d<sub>8</sub> in the temperature range -80°C to +85°C for the phenyl and p-tolyl compounds were as expected for a mixture of anti and gauche rotamers with proximal  $\rightleftharpoons$  distal N-methyl exchange being frozen out at low temperatures. The low temperature limiting spectrum for the p-tolyl compound is shown in Figure 8. The <sup>1</sup>H signals for the ortho and meta hydrogens fall into two types which, by comparison with the integral intensity of the N-methyl groups, may be assigned to anti and gauche molecules. Significantly, these signals shown little temperature dependence which, in view of the large diamagnetic anisotropy associated with the M≡M bond<sup>14</sup> and the positioning of the ortho protons seen in the solid state for the anti-rotamer, suggests a very low barrier to rotation about the Mo-C (aryl) bonds. Even at 500 MHz and -90°C, the spectrum showed no evidence for restricted rotation about these bonds. This observation prompted us to prepare the ortho-tolyl compound: the ortho-methyl group was expected to have a site preference either proximal or distal (the latter seeming more likely) to the M≡M bond. A further check on McGlinchey's<sup>14</sup> calculation of  $\chi_{(M\equiv M)}$  for M = Mo and W would be interesting for these types of compounds. Although the synthesis of the o-tolyl compounds was straightforward, the <sup>1</sup>H nmr spectra revealed the presence of only the gauche rotamer in solution. See Figure 9. Furthermore, the signals associated with the ortho-tolyl ligand were relatively independent of temperature and did not reveal any significant influence of the M M bond. This implied either 50:50 proximal to distal site preference for the methyl group and facile rotation about the Mo-C bond or that the o-tolyl ligands were aligned with their planes perpendicular to the

Mo-Mo-C plane. The latter is found in the solid state and seems most likely to account for the observed  $^1\text{H}$  nmr spectra.

Although we have not been able to isolate a mesityl compound  $1,2\text{-M}_2(\text{C}_6\text{H}_2\text{Me}_3)_2(\text{NMe}_2)_4$  as a crystalline compound,  $^1\text{H}$  nmr spectra recorded on the hexane soluble extractions of reaction 1 employing  $\text{LiC}_6\text{H}_2\text{Me}_3$  suggest that these compounds ( $\text{M} = \text{Mo}$  and  $\text{W}$ ) may be formed and, if so, in solution they exist in the gauche rotamer. Moreover, only one ortho-methyl resonance signal was seen, which implies rapid (nmr time scale) rotation about the M-C (aryl) bonds.

#### Concluding Remarks

(1) The metal atoms in  $1,2\text{-M}_2\text{R}_2(\text{NMe}_2)_4$  compounds ( $\text{M} = \text{Mo}, \text{W}$ ) have 16 valence electrons as a result of forming a  $\text{M}\equiv\text{M}$  bond ( $\sigma$  ( $d_{z^2}-d_{z^2}$ ) and  $\pi$  ( $d_{xz}-d_{xz}, d_{yz}-d_{yz}$ )), three M-L  $\sigma$  bonds (metal s,  $p_x, p_y$ ) and two M+L  $\pi$  bonds (involving metal  $d_{x^2-y^2}, d_{xy}$ ).<sup>15</sup> Only the metal  $p_z$  atomic orbital is not used in bonding. The characterization of the  $\sigma$ -benzyl complexes reported herein supports the previous conclusions concerning the stability of  $\beta$ -hydrogen containing alkyl compounds  $\text{M}_2\text{R}_2(\text{NMe}_2)_4$ : C-H activation does not occur readily because the metal atomic orbitals are either tied up in bonding ( $\text{M}\equiv\text{M}$ , M-C,  $\text{M}=\text{N}$  ( $\sigma + \pi$ )) or apparently not suited for receiving an electron pair, as is the case for the  $p_z$  atomic orbital which lies along the M-M axis.

(2)  $1,2\text{-M}_2\text{R}_2(\text{NMe}_2)_4$  compounds exist in the ground state in conformers which have the  $\text{NC}_2$  blades aligned along the M-M axis. In such conformers, the M-M  $\pi$ -bonds and M-N  $\pi$ -bonds are not in competition for use of the same metal atomic orbitals. The relatively high M-N rotational

barriers<sup>16</sup> result from electronic factors and the marked preference for a M=M bond in which the  $\pi$  bonds use  $d_{xz}$  and  $d_{yz}$  metal atomic orbitals. Computational studies, using full relaxation empirical force field (EFF) calculations, on hexaaryl ethanes reveal two potential energy minima, one corresponding to a  $D_3$  structure composed of two essentially eclipsed homochiral triaryl propellers and the other to an  $S_6$  structure composed of two staggered heterochiral propellers.<sup>17</sup> In both conformers, the dihedral angle between the  $C_{sp^3}-C_{sp^3}-C_{aryl}$  plane and the respective plane of the aryl group was ca.  $50^\circ$ . On purely steric grounds, similar conformational preferences would be expected for  $M_2(aryl)_2(NMe_2)_4$  compounds.

We conclude that  $Me_2N$ -to-M  $\pi$ -bonding produces pronounced effects in ground state conformations, dynamic solution behavior and reactivity patterns for the 16 electron valence shell molybdenum and tungsten compounds  $M_2R_2(NMe_2)_4$ . The stabilization of the 16 electron complexes relative to 18 electron complexes is presumably due to M-M  $\sigma$  versus M-L bond formation (competition) in use of the  $d_{z^2}-p_z$  atomic orbitals. This preference is well illustrated by the  $W_2(O_2CNMe_2)_6$  structure in which five in-plane pentagonal hybrid tungsten orbitals ( $s$ ,  $p_x$ ,  $p_y$ ,  $d_{x^2-y^2}$ ,  $d_{xy}$ ) are used to form five strong W-O bonds ( $W-O = 2.1 \text{ \AA}$  (averaged)) while the sixth W-O bond, which is aligned along the W-W axis, is weak ( $W---O = 2.67 \text{ \AA}$ ).<sup>18</sup>

### Experimental Section

All reactions were carried out under anaerobic conditions using prepurified nitrogen and standard Schlenk and glovebox techniques. Hexane and toluene were distilled under  $N_2$  over Na/K alloy. Glassware was flame dried in vacuo before use.  $^1H$  nmr spectra were recorded on a Varian HR 220 MHz, a Nicolet 360 MHz or a Bruker 500 MHz nmr spectrometer, all equipped with variable temperature probes. All spectra were run using  $d^8$ -toluene as the solvent, with the  $CHD_2$  protio impurity set as the reference peak at 2.09 ppm.  $^1H$  nmr data are quoted in  $\delta$  ppm relative to  $Me_4Si$  and  $J$  in Hz. Infrared spectra were obtained from Nujol mulls between KBr plates (unless otherwise stated) using a Perkin Elmer 283 spectrophotometer. I.r. data are quoted in  $\bar{\nu}$   $cm^{-1}$ . Elemental analyses were performed by Alfred Bernhardt Mikroanalytisches Laboratorium, Elbach, West Germany. Mass spectra were obtained on a Varian MS-902 by the method of direct insertion, courtesy of Mr. Peter Cook, Queen Mary College, London.

$PhLi$  (1.9 M in 70/30 benzene:diethylether),  $BuLi$  (2.4 M in hexane),  $MeLi$  (1.6 M in diethylether) and all aryl-bromides and -iodides were purchased from Aldrich Chem. Co. Benzyl lithium was synthesized by reacting  $(PhCH_2)_3SnCl$  with  $MeLi$ , as described in the literature.<sup>19</sup> Benzyl magnesium chloride was prepared as reported,<sup>20</sup> the solvent removed, and the solid residue extracted with toluene, concentrated and crystallized.

Synthesis of aryllithium reagents. Lithium aryls were synthesized by reacting the appropriate aryl-bromide or -iodide with butyllithium in

hexane. The often vigorous reaction was moderated by cooling in an ice bath and adding the organolithium reagent over a 15 minute period. A typical synthesis is described below.

Synthesis of p-tolyl lithium. p-Tolyl bromide (17.104 g, 100 mmoles) was placed in a 250 mL two-necked round-bottomed flask under nitrogen, and freeze-thaw degassed (3 cycles). BuLi (100 mmoles, 42 mL of a 2.4 M solution in hexane) was added over 15 min, while cooling the bromide in an ice bath. A yellowish solution formed, which deposited a creamy white ppt. over a 6 hour period. The precipitate was collected by filtration, washed with 2 x 10 mL hexane and dried under vacuum. Yield 7.36 g (75%).

Synthesis of 1,2-Mo<sub>2</sub>(CH<sub>2</sub>Ph)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub>. Mo<sub>2</sub>Cl<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub><sup>21</sup> (500 mgs, 1.14 mmole) was placed in a 100 mL round-bottomed flask, with a teflon-coated magnetic stirring bar. Toluene (50 mL) was added, and the solution cooled to -78°C. Solid benzyl-Grignard (400 mgs, excess) was added over 30 min, through a solid addition tube. The reaction mixture was then warmed to room temperature and stirred for 8 h. The toluene was then stripped, hexane (50 mL) added, and the hexane solution filtered through a fine frit, yielding a dark yellow solution. Cooling at 0°C for 3 days afforded dark yellow crystals in 60% yield (330 mg).

I.r. data (CsI plates): 1584 s, 1480 s, 1416 s, 1375 s, 1158 s, 1140 s, 1137 s, 1120 w, 1100 w, 1087 s, 1048 s, 1023 s, 967 w, 937 vs, 887 w, 792 s, 747 s, 690 s, 598 w, 535 w, 442 m, 395 w, 342 w, 316 w.

Mass spectroscopy: m/e 550.9 (M+).

$^1\text{H}$  nmr data ( $-75^\circ\text{C}$ , 360 MHz): 7.19 (m, Ph), 6.85 (m, Ph), 4.18, 3.53 ( $[\text{AB}]_2$  spin system,  $\text{CH}_2$  gauche rotamer,  $J(\text{AB})$  12 Hz), 3.73 ( $\text{CH}_2$  anti-rotamer), 4.10, 3.90 ( $\text{NMe}$ , proximal, gauche rotamer), 4.07 ( $\text{NMe}$ , proximal, anti), 2.25, 2.00 ( $\text{NMe}$ , distal, gauche), 2.19 ( $\text{NMe}$ , distal, anti).

The compound  $1,2\text{-Mo}_2(\text{CH}_2\text{C}_6\text{H}_4\text{Me-4})_2(\text{NMe}_2)_4$  was prepared in a similar fashion. Spectroscopic data are listed below.

I.r. data (CsI plates): 1600 m, 1503 m, 1413 m, 1372 s, 1255 m, 1235 m, 1206 w, 1186 m, 1171 w, 1142 m, 1108 m, 1073 m, 1012 m, 983 m, 938 vs, 833 w, 803 s, 727 m, 713 m, 596 w, 555 m, 530 m, 483 m, 447 m, 412 w, 331 m.

$^1\text{H}$  nmr data ( $-50^\circ\text{C}$ , 220 MHz): 6.90 (m, Ph), 4.11, 3.56 ( $[\text{AB}]_2$  spin system,  $\text{CH}_2$  gauche,  $J(\text{AB})$  12), 4.09, 3.89 ( $\text{NMe}$ , proximal, gauche), 4.05 ( $\text{NMe}$ , proximal, anti), 3.69 ( $\text{CH}_2$ , anti), 2.26, 2.19 ( $\text{NMe}$ , distal, gauche), 2.15 ( $\text{NMe}$ , distal, anti), 2.10 ( $\text{C}_6\text{H}_4\text{Me-4}$ , anti and gauche resonances fortuitously coincident).

Synthesis of  $1,2\text{-W}_2(\text{CH}_2\text{Ph})_2(\text{NMe}_2)_4$ .  $\text{W}_2\text{Cl}_2(\text{NMe}_2)_4^{21}$  (1.23 g, 2 mmole) was placed in a Schlenk tube. Benzylolithium (60 mL of a 0.074 M solution in toluene/hexane, 4.44 mmole) was added. The orange solution darkened to brown within minutes as the  $\text{W}_2\text{Cl}_2(\text{NMe}_2)_4$  reacted, and was stirred for 2 h. The solvent was removed in vacuo and the solid residue extracted with hexane, and filtered through a celite pad and a medium porosity frit. The orange-brown solution deposited crystals on concentration and cooling at  $-20^\circ\text{C}$ . Yield 81% (1.18 g).



I.r. data: 3065 w, 3050 w, 3010, m, 2816 m, 2770 s, 1593 m, 1570 w, 1483 m, 1448 m, 1417 m, 1390 vw, 1243 s, 1196 m, 1170 w, 1141 m, 1121 w, 1086 w, 1038 m, 1028 m, 1012 m, 989 w, 952 vs, 944 vs, 789 m, 750 s, 682 s.

Nmr data ( $-45^{\circ}\text{C}$ , 220 MHz): 7.20–6.89 (m, Ph), 4.19, 4.02 (NMe, proximal, gauche), 4.14 (NMe, proximal, anti), 4.08, 3.31 ( $[\text{AB}]_2$  spin system,  $\text{CH}_2$  gauche,  $J(\text{AB})$  14), 3.62 ( $\text{CH}_2$ , anti), 2.19, 1.99 (NMe, distal, gauche), 2.11 (NMe, distal, anti).

Synthesis of  $1,2\text{-Mo}_2\text{Ph}_2(\text{NMe}_2)_4$ .  $1,2\text{-Mo}_2\text{Cl}_2(\text{NMe}_2)_4$  (878 mg, 2 mmole) was added to solid PhLi (4.5 mmole, 378 mg) in a Schlenk tube. Hexane (50 mL) was added and the mixture stirred magnetically for 3 h, yielding a cloudy brownish solution. Filtration through a Celite pad afforded a yellowish-brown solution, which deposited dark yellow crystals on concentration and cooling overnight at  $-20^{\circ}\text{C}$ . Yield 77% (800 mg).

I.r. data: 3043 m, 2814 s, 2770 s, 1420 m, 1416 m, 1393 vw, 1375 w, 1260 m, 1240 s, 1183 w, 1143 s, 1114 w, 1090 w br, 1057 w, 1046 w, 1037 m, 1016 vw, 990 w, 940 vs br, 795 m br, 730 vw, 720 s, 691 s, 659 w, 644 w, 555 w.

Nmr data: ( $-45^{\circ}\text{C}$ , 220 MHz): 8.05–7.99, 7.52–7.29 (m, anti, gauche Ph), 4.10, 4.03 (NMe, proximal, gauche), 4.03 (NMe, proximal, anti), 2.57, 2.47 (NMe, distal, gauche), 2.49 (NMe, distal, anti).

$1,2\text{-W}_2\text{Ph}_2(\text{NMe}_2)_4$ . Synthesized as described above for the Mo compound, but employing  $\text{W}_2\text{Cl}_2(\text{NMe}_2)_4$ .

I.r. data: 3045 m, 2822 m, 2780 ms, 1522 w, 1469 w, 1448 m, 1421 m, 1405 m, 1392 w, 1385 m, 1258 w, 1244 s, 1187 w, 1144 w, 1123 w, 1063 m, 1051 m, 1037 m, 1018 vw, 989 w, 955 vs, 940 vs, 800 m br, 694 s, 660 w, 650 w.

$^1\text{H}$  nmr data ( $-45^\circ\text{C}$ , 220 MHz): 8.15–7.92, 7.54–7.18 (m, Ph, anti, gauche), 4.19, 4.12 (NMe, proximal, gauche), 4.10 (NMe, proximal, anti), 2.48, 2.43 (NMe, distal, gauche), 2.30 (NMe, distal, anti).

Synthesis of  $1,2\text{-Mo}_2(\text{C}_6\text{H}_4\text{Me-2})_2(\text{NMe}_2)_4$ . o-Tolylolithium (4 mmole, 392 mgs) was placed in a Schlenk tube, followed by  $\text{Mo}_2\text{Cl}_2(\text{NMe}_2)_4$  (2 mmole, 878 mgs). Hexane (100 mL) was added, and the suspension stirred overnight. Filtration through a medium porosity frit yielded an orange solution which precipitated large golden crystals on concentration and cooling overnight at  $-5^\circ\text{C}$ . Yield 85% (620 mg).

I.r. data: 3043, m, 3036 m, 3029 m, 2988 w, 2823 s, 2770 s, 1566 w, 1450 m, 1434 m, 1409 m, 1390 m, 1268 w, 1257 m, 1238 s, 1190 vw, 1146 vs, 1118 vw, 1104 w, 1037 m, 1033 m, 1018 vw, 962 vw, 951 vs, 947 vs, 936 vs, 852 vw, 795 m br, 784 m, 733 s sh, 730 vs, 701 w, 658 vw, 574 w.

Nmr data ( $-45^\circ\text{C}$ , 220 MHz): 7.91–7.86, 7.36–7.18 (m, aromatic H), 4.18, 4.10 (NMe, proximal), 2.47, 2.26 (NMe, distal), 2.14 ( $\text{C}_6\text{H}_4\text{Me-2}$ ).

$1,2\text{-W}_2(\text{C}_6\text{H}_4\text{Me-2})_2(\text{NMe}_2)_4$  was prepared in an analogous manner using  $\text{W}_2\text{Cl}_2(\text{NMe}_2)_4$ .

I.r. data: 3041 w, 3022 w, 2805 m, 2762 m, 1571 w, 1413 m, 1390 w, 1258 m, 1244 s, 1144 m, 1123 w, 1106 w, 1036 m, 1027 w, 949 vs, 935 vs, 797 m br, 735 vs, 707 m.

$^1\text{H}$  nmr data ( $-45^\circ\text{C}$ , 220 MHz): 7.64–7.62, 7.34–7.24, 7.11–7.04 (m, aromatic CH), 4.21 (NMe, proximal), 2.27, 2.14 (NMe, distal), 1.98 ( $\text{C}_6\text{H}_4\text{Me}-2$ ).

Synthesis of  $1,2\text{-W}_2(\text{C}_6\text{H}_4\text{Me}-4)_2(\text{NMe}_2)_4$ .  $\text{W}_2\text{Cl}_2(\text{NMe}_2)_4$ <sup>21</sup> (615 mgs, 1 mmole) was suspended in 40 mL hexane. Solid  $\text{LiC}_6\text{H}_4\text{Me}-4$  (205 mg, 2.1 mmole) was added, and the solution stirred overnight, yielding a dirty brown solution. Filtration through a Celite pad removed the insoluble  $\text{LiCl}$  and any excess tolyllithium. The residue was washed with hexane (20 mL) and the washings combined with the filtrate, yielding a reddish brown solution. Concentration in vacuo and overnight crystallization afforded a crop of reddish-brown microcrystals. Yield ca. 84% (615 mgs).

I.r. data: 3034 w, 2809 m, 2763 m, 1581 w, 1477 w, 1444 w, 1422 vw, 1392 vw, 1375 m, 1300 w, 1260 m, 1241 m, 1180 m, 1140 m, 1050 m, 1036 m, 1012 w, 951 vs, 938 vs, 795 m br, 781 s, 660 w.

$^1\text{H}$  nmr data ( $-60^\circ$ , 360 MHz): 8.02, 7.38 ( $[\text{AB}]_2$  spin system, aromatic o- and m- H, anti, J (AB) 9), 7.98, 7.27 ( $[\text{AB}]_2$  spin system, aromatic o- and m- H, gauche, J (AB) 8), 4.25, 4.16 (NMe, proximal, gauche), 4.18 (NMe, proximal, anti), 2.54, 2.43 (NMe, distal, gauche), 2.50 (NMe, distal, anti), 2.32 ( $\text{C}_6\text{H}_4\text{Me}-4$ , anti), 2.26 ( $\text{C}_6\text{H}_4\text{Me}-4$ , gauche).

$1,2\text{-Mo}_2(\text{C}_6\text{H}_4\text{Me}-4)_2(\text{NMe}_2)_4$  was made in similar fashion to the tungsten analogue employing  $\text{Mo}_2\text{Cl}_2(\text{NMe}_2)_4$ <sup>21</sup>.

I.r. data: 3027 w, 3014 w, 2809 m, 2764 m, 1580 w, 1479 w, 1445 m, 1414 m, 1393 vw, 1300 vw, 1258 m, 1236 m, 1180 m, 1140 m, 1088 w br, 1045 m, 1038 m, 1015 vw, 949 s, 938 vs, 796 m, 783 s, 658 w.

$^1\text{H}$  nmr data ( $-80^\circ$ , 500 MHz): 8.01, 7.19 ( $[\text{AB}]_2$  spin system, aromatic o-, m- H, gauche,  $J(\text{AB})$  8), 7.99, 7.32 ( $[\text{AB}]_2$  spin system, aromatic o-, m- H, anti,  $J(\text{AB})$  8), 4.16, 4.08 ( $\text{NMe}$ , proximal, gauche), 4.07 ( $\text{NMe}$ , proximal, anti), 2.62, 2.53 ( $\text{NMe}$ , distal, gauche), 2.55 ( $\text{NMe}$ , distal, anti), 2.33 ( $\text{C}_6\text{H}_4\text{Me}$ -4, anti), 2.26 ( $\text{C}_6\text{H}_4\text{Me}$ -4, gauche).

Reaction of mesityllithium with  $1,2\text{-W}_2\text{Cl}_2(\text{NMe}_2)_4$ .  $1,2\text{-W}_2\text{Cl}_2(\text{NMe}_2)_4$ <sup>21</sup> (615 mg, 1 mmole) was suspended in hexane (30 mL). Mesityllithium ( $\text{LiC}_6\text{H}_2\text{Me}_3$ -2,4,6, 252 mg, 2 mmole) was added and the solution stirred for 3 days. The brownish solution was then filtered; the residue appeared to contain unreacted  $1,2\text{-W}_2\text{Cl}_2(\text{NMe}_2)_4$  in addition to LiCl. The red filtrate was concentrated and a few crystals of  $1,2\text{-W}_2\text{Cl}_2(\text{NMe}_2)_4$  formed. No further products could be crystallized, oils being formed on further concentration. The oily red product was pumped for 2 days under high vacuum, yielding a reddish-brown solid.  $^1\text{H}$  nmr suggested the presence of  $1,2\text{-W}_2(\text{C}_6\text{H}_2\text{Me}_3\text{-2,4,6})_2(\text{NMe}_2)_4$ , together with other uncharacterized compounds. Repeated attempts to purify and isolate this compound, for both molybdenum and tungsten, were unsuccessful.

#### X-ray Structural Determinations

General procedures have been described previously.<sup>22</sup>

$1,2\text{-Mo}_2(\text{CH}_2\text{C}_6\text{H}_5)_2(\text{NMe}_2)_4$ . A yellow crystal of dimensions 0.18 x 0.18 x 0.24 mm was cleaved from a larger crystal, mounted in a nitrogen-filled glovebag and transferred to the liquid nitrogen boiloff system of the diffractometer, where cell dimensions were obtained at  $-165^\circ\text{C}$ . The

space group was found to be  $P2_1/a$  with  $a = 17.595(7) \text{ \AA}$ ,  $b = 16.038(6) \text{ \AA}$ ,  $c = 10.542(4) \text{ \AA}$ ,  $\beta = 122.11(2)^\circ$ ,  $V = 2519.81 \text{ \AA}^3$ ,  $Z = 4$ ,  $d_{\text{calcd}} = 1.451 \text{ g cm}^{-3}$  using  $\text{Mo K}\alpha$  ( $\lambda = 0.71069 \text{ \AA}$ ),  $\mu = 9.854$ .

Data were collected at  $-165^\circ\text{C}$ . Of a total of 5121 reflections, 4431 unique reflections were measured, using moving-crystal, moving-counter techniques. The scan speed =  $4.0 \text{ deg min}^{-1}$ ; scan width =  $1.8 + \text{dispersion}$ ; single background time at extremes of scan =  $5 \text{ s}$ ; aperture size =  $3.0 \times 4.0 \text{ mm}$ . A total of 3666 reflections had  $F > 2.33\sigma(F)$ ; these were used in the refinement. The limits of data collection were  $5^\circ < 2\theta < 50^\circ$ .

The structure was solved using conventional Patterson and Fourier techniques. Refinement, using standard full matrix least-squares cycles located all atoms including hydrogens. These were refined isotropically while all other atoms were refined anisotropically. Refinement converged at  $R(F) = 0.036$ ,  $R_w(F) = 0.038$ . The goodness of fit for the last cycle was 1.012, while the maximum  $\Delta/\sigma = 0.10$ .

$1,2\text{-Mo}_2(\text{C}_6\text{H}_4\text{Me-4})_2(\text{NMe}_2)_4$ . The sample used in the study was cleaved from a larger needle and transferred to the goniostat using standard inert atmosphere handling techniques. Data were collected at  $-162^\circ$  and yielded the following cell dimensions from a reciprocal-space search: space group =  $P_{\text{can}}$ ;  $a = 8.046(2) \text{ \AA}$ ,  $b = 17.319(7) \text{ \AA}$ ,  $c = 18.179(8)$ ,  $V = 2533.2 \text{ \AA}^3$ ,  $Z = 4$ ,  $d_{\text{calcd}} = 1.443 \text{ g cm}^{-3}$ , using  $\text{Mo K}\alpha$  ( $\lambda = 0.71069 \text{ \AA}$ ),  $\mu = 9.802$ , scan speed =  $4.0 \text{ deg min}^{-1}$ , scan width =  $2.0 + \text{dispersion}$ , single background at extremes of scan =  $5 \text{ s}$ , aperture size =  $3.0 \times 4.0 \text{ mm}$ ,  $5^\circ < 2\theta < 50^\circ$ .

Of a total of 3688 reflections, 2250 were unique, and 1864 had  $F > 2.33\sigma(F)$ ; the latter were used in refinement. The structure was solved by direct methods and refined by full matrix least squares, using isotropic thermal parameters for hydrogens. The structure converged at  $R(F) = 0.038$ ,  $R_w(F) = 0.026$ , there being no peak greater than  $0.42 \text{ e } \text{\AA}^{-3}$  in the final difference Fourier map. The goodness of fit for the last cycle was 3.397, while the maximum  $\Delta/\sigma = 0.05$ .

1,2-Mo<sub>2</sub>(C<sub>6</sub>H<sub>4</sub>Me-2)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub>. Golden crystals of the titled compound were grown from hexane. A crystal was mounted on the diffractometer as described for the previous structures. Cell dimensions and data were collected at  $-161^\circ\text{C}$  and are as follows: space group  $A2/a$ ,  $a = 16.845(4)$ ,  $b = 17.651(5)$ ,  $c = 8.451(2)$ ,  $\beta = 102.74(1)^\circ$ ,  $V = 2451.0 \text{ \AA}^3$ ,  $Z = 4$ ,  $d_{\text{calcd}} = 1.492 \text{ g cm}^{-3}$ , using Mo  $K\alpha$  radiation ( $\lambda = 0.71069 \text{ \AA}$ ),  $\mu = 10.130$ , scan speed =  $3.0 \text{ deg min}^{-1}$ , scan width =  $2.0 + \text{dispersion}$ , single background time at extremes of scan = 5 s, aperture size =  $3.0 \times 6.0 \text{ mm}$ .

The total number of reflections collected was 2568 with  $5^\circ < 2\theta < 50^\circ$ . Out of 2171 unique intensities, 1892 had  $F > 2.33\sigma(F)$ ; these were used in solving the structure. The position of all atoms was determined using direct methods and full matrix least squares. Hydrogen atoms were refined isotropically, while for all other atoms anisotropic thermal parameters were used. Refinement converged at  $R(F) = 0.033$ ,  $R_w(F) = 0.023$ , with the goodness of fit for the last cycle being 2.981 and the maximum  $\Delta/\sigma = 0.05$ . A final difference Fourier synthesis was featureless, the largest peak being  $0.45 \text{ e } \text{\AA}^{-3}$ .

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Supplementary Material Available. Tables of observed and calculated structure factor amplitudes and anisotropic thermal parameters for the 1,2- $M_2R_2(NMe_2)_4$  compounds where  $R = CH_2C_6H_5$ ,  $C_6H_5Me-2$  and  $C_6H_5Me-4$  (xxx pages). Ordering information is given on any current masthead page.

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Table I. Analytical and Other Characterization Data for the 1,2-M<sub>2</sub>R<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> Compounds (M = Me, W).

Compound	Color	Yield <sup>a</sup>	Elemental Analyses Found (Calcd)		
			C	H	N
Mo <sub>2</sub> (Cl <sub>2</sub> Ph) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	golden-yellow	60	47.77 (48.00)	6.83 (6.95)	10.27 (10.18)
W <sub>2</sub> (CH <sub>2</sub> Ph) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	brownish-yellow	81	36.51 (36.38)	5.08 (5.27)	7.73 (7.71)
Mo <sub>2</sub> (CH <sub>2</sub> C <sub>6</sub> H <sub>4</sub> Me-4) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	yellow	62	49.52 (49.83)	7.20 (7.32)	9.52 (9.68)
Mo <sub>2</sub> Ph <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	yellow	77	45.85 (45.98)	6.36 (6.56)	10.59 (10.72)
W <sub>2</sub> Ph <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	orange-yellow	73	34.91 (34.40)	4.99 (4.91)	8.19 (8.02)
Mo <sub>2</sub> (C <sub>6</sub> H <sub>4</sub> Me-2) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	golden	88	48.06 (48.00)	6.89 (6.95)	10.26 (10.19)
W <sub>2</sub> (C <sub>6</sub> H <sub>4</sub> Me-2) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	red	80	37.89 (36.38)	5.62 (5.27)	7.57 (7.71)
Mo <sub>2</sub> (C <sub>6</sub> H <sub>4</sub> Me-4) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	orange	78	47.69 (48.00)	6.77 (6.95)	10.50 (10.18)
W <sub>2</sub> (C <sub>6</sub> H <sub>4</sub> Me-4) <sub>2</sub> (NMe <sub>2</sub> ) <sub>4</sub>	brick-red	84	36.89 (36.38)	5.62 (5.27)	7.57 (7.71)

<sup>a</sup>% yield based on eq. 1.

Table II. Fractional Coordinates and Isotropic Thermal Parameters for the  
1,2-Mo<sub>2</sub>(benzyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> Molecule.

Atom	x	y	z	B <sub>iso</sub>
Mo(1)	1046.0(2)	1790.5(2)	-473.2(4)	11
Mo(2)	-143.4(2)	1873.1(2)	-2757.7(4)	13
N(3)	571(2)	1718(2)	824(4)	15
C(4)	-323(3)	1791(3)	580(6)	24
C(5)	1239(3)	1685(3)	2437(5)	22
N(6)	1778(2)	2735(2)	-350(4)	16
C(7)	1619(4)	3447(3)	-1326(6)	26
C(8)	2633(3)	2834(3)	1081(6)	22
C(9)	1601(3)	592(3)	-626(5)	15
C(10)	2532(3)	592(3)	670(5)	15
C(11)	3240(3)	879(3)	554(5)	18
C(12)	4114(3)	899(3)	1778(6)	22
C(13)	4305(3)	632(3)	3178(6)	23
C(14)	3604(3)	349(3)	3311(5)	20
C(15)	2741(3)	326(3)	2090(5)	17
N(16)	349(2)	1845(2)	-4040(4)	16
C(17)	1245(3)	1905(3)	-3775(5)	21
C(18)	-328(4)	1907(3)	-5648(5)	26
N(19)	-759(3)	2865(3)	-2683(4)	21
C(20)	-1580(4)	3099(4)	-4077(7)	31
C(21)	-486(4)	3525(3)	-1557(6)	27
C(22)	-800(3)	700(3)	-2852(5)	22
C(23)	-1671(3)	688(3)	-4292(5)	18
C(24)	-2444(3)	1058(3)	-4469(5)	19
C(25)	-3251(3)	1061(3)	-5830(6)	21
C(26)	-3324(3)	700(3)	-7081(5)	23
C(27)	-2569(3)	336(3)	-6944(6)	23
C(28)	-1765(3)	329(3)	-5584(5)	19

Notes: (1) Fractional coordinates are  $\times 10^4$ . B<sub>iso</sub> values are  $\times 10$ .

(2) Isotropic values for those atoms refined anisotropically are calculated using the formula given by W.C. Hamilton, Acta Cryst. 1959, 12, 609.

Table III. Bond Distance ( $\text{\AA}$ ) for the  $1,2\text{-Mo}_2(\text{benzyl})_2(\text{NMe}_2)_4$  Molecule.

A	B	Distance	A	B	Distance
Mo(1)	Mo(2)	2.200(1)	C(9)	C(10)	1.474(6)
Mo(1)	N(3)	1.949(3)	C(10)	C(11)	1.392(6)
Mo(1)	N(6)	1.948(4)	C(10)	C(15)	1.404(6)
Mo(1)	C(9)	2.201(5)	C(11)	C(12)	1.386(7)
Mo(2)	N(16)	1.956(4)	C(12)	C(13)	1.396(7)
Mo(2)	N(19)	1.949(4)	C(13)	C(14)	1.390(7)
Mo(2)	C(22)	2.182(5)	C(14)	C(15)	1.373(6)
N(3)	C(4)	1.457(6)	C(22)	C(23)	1.477(6)
N(3)	C(5)	1.466(6)	C(23)	C(24)	1.402(6)
N(6)	C(7)	1.462(6)	C(23)	C(28)	1.405(7)
N(6)	C(8)	1.466(6)	C(24)	C(25)	1.382(7)
N(16)	C(17)	1.451(6)	C(25)	C(26)	1.382(7)
N(16)	C(18)	1.467(6)	C(26)	C(27)	1.386(7)
N(19)	C(20)	1.460(6)	C(27)	C(28)	1.379(7)
N(19)	C(21)	1.468(7)			

Table IV. Bond Angles (deg.) for the 1,2-Mo<sub>2</sub>(benzyl)<sub>2</sub>-(NMe<sub>2</sub>)<sub>4</sub> Molecule.

A	B	C	Angle
Mo(2)	Mo(1)	N(3)	105.0(1)
Mo(2)	Mo(1)	N(6)	103.7(1)
Mo(2)	Mo(1)	C(9)	100.0(1)
N(3)	Mo(1)	N(6)	121.0(2)
N(3)	Mo(1)	C(9)	111.8(2)
N(6)	Mo(1)	C(9)	112.4(2)
Mo(1)	Mo(2)	N(16)	104.0(1)
Mo(1)	Mo(2)	N(19)	103.3(1)
Mo(1)	Mo(2)	C(22)	99.8(1)
N(16)	Mo(2)	N(19)	120.4(2)
N(16)	Mo(2)	C(22)	111.5(2)
N(19)	Mo(2)	C(22)	114.4(2)
Mo(1)	N(3)	C(4)	134.1(3)
Mo(1)	N(3)	C(5)	116.0(3)
C(4)	N(3)	C(5)	109.4(4)
Mo(1)	N(6)	C(7)	133.5(3)
Mo(1)	N(6)	C(8)	115.7(3)
C(7)	N(6)	C(8)	110.3(4)
Mo(2)	N(16)	C(17)	134.4(3)
Mo(2)	N(16)	C(18)	114.3(3)
C(17)	N(16)	C(18)	110.5(4)
Mo(2)	N(19)	C(20)	116.4(4)
Mo(2)	N(19)	C(21)	132.2(3)
C(20)	N(19)	C(21)	110.5(4)
Mo(1)	C(9)	C(10)	104.5(3)
C(9)	C(10)	C(11)	121.6(4)
C(9)	C(10)	C(15)	121.4(4)
C(11)	C(10)	C(15)	117.0(4)
C(10)	C(11)	C(12)	121.9(4)
C(11)	C(12)	C(13)	120.1(4)
C(12)	C(13)	C(14)	118.6(4)
C(13)	C(14)	C(15)	120.8(4)
C(10)	C(15)	C(14)	121.6(4)
Mo(2)	C(22)	C(23)	107.1(3)
C(22)	C(23)	C(24)	122.3(4)
C(22)	C(23)	C(28)	121.6(4)
C(24)	C(23)	C(28)	116.0(4)
C(23)	C(24)	C(25)	121.9(4)
C(24)	C(25)	C(26)	120.8(4)
C(25)	C(26)	C(27)	118.7(4)
C(26)	C(27)	C(28)	120.6(4)
C(23)	C(28)	C(27)	122.1(4)

Table V. Fractional Coordinates and Isotropic Thermal Parameters for the  $\text{Mo}_2(\text{p-tolyl})_2(\text{NMe}_2)_4$  Molecule.

Atom	x	y	z	B <sub>iso</sub>
Mo(1)	4335.0(4)	4516.2(2)	-256.4(2)	14
N(2)	2927(4)	5012(2)	-985(2)	19
N(3)	6098(4)	3812(2)	-566(2)	18
C(4)	2828(6)	5796(3)	-1270(3)	26
C(5)	1888(6)	4492(3)	-1424(2)	29
C(6)	7893(6)	3834(3)	-539(3)	26
C(7)	5544(6)	3173(2)	-1026(2)	25
C(8)	2964(5)	4057(2)	664(2)	18
C(9)	2846(5)	4324(2)	1391(2)	20
C(10)	1973(6)	3932(2)	1927(2)	24
C(11)	1146(5)	3249(2)	1765(2)	22
C(12)	1230(5)	2976(2)	1051(2)	23
C(13)	2116(5)	3374(2)	521(2)	22
C(14)	210(8)	2818(3)	2349(3)	34

Notes: (1) Fractional coordinates are  $\times 10^4$ . B<sub>iso</sub> values are  $\times 10$ .

(2) Isotropic values for those atoms refined anisotropically are calculated using the formula given by W.C. Hamilton, Acta Cryst. 1959, 12, 609.

Table VI. Bond Distances ( $\text{\AA}$ ) for the  $\text{Mo}_2(\text{p-tolyl})_2(\text{NMe}_2)_4$  Molecule.

A	B	Distance	A	B	Distance
Mo(1)	Mo(1)'	2.196(1)	C(8)	C(9)	1.404(5)
Mo(1)	N(2)	1.943(3)	C(8)	C(13)	1.390(5)
Mo(1)	N(3)	1.954(3)	C(9)	C(10)	1.379(6)
Mo(1)	C(8)	2.156(4)	C(10)	C(11)	1.389(6)
N(2)	C(4)	1.457(5)	C(11)	C(12)	1.383(6)
N(2)	C(5)	1.465(5)	C(11)	C(14)	1.500(6)
N(3)	C(6)	1.445(5)	C(12)	C(13)	1.383(6)
N(3)	C(7)	1.456(5)			

Table VII. Bond Angles (deg) for the  $\text{Mo}_2(\text{p-tolyl})_2\text{-(NMe}_2)_4$  Molecule.

A	B	C	Angle
Mo(1)'	Mo(1)	N(2)	103.7(1)
Mo(1)'	Mo(1)	N(3)	104.2(1)
Mo(1)'	Mo(1)	C(8)	101.6(1)
N(2)	Mo(1)	N(3)	120.2(1)
N(2)	Mo(1)	C(8)	113.2(1)
N(3)	Mo(1)	C(8)	111.4(1)
Mo(1)	N(2)	C(4)	133.4(3)
Mo(1)	N(2)	C(5)	115.7(3)
C(4)	N(2)	C(5)	110.3(3)
Mo(1)	N(3)	C(6)	134.3(3)
Mo(1)	N(3)	C(7)	114.7(3)
C(6)	N(3)	C(7)	110.3(3)
Mo(1)	C(8)	C(9)	130.1(3)
Mo(1)	C(8)	C(13)	114.9(3)
C(9)	C(8)	C(13)	115.0(3)
C(8)	C(9)	C(10)	122.5(4)
C(9)	C(10)	C(11)	120.9(4)
C(10)	C(11)	C(12)	117.8(4)
C(10)	C(11)	C(14)	121.0(4)
C(12)	C(11)	C(14)	121.2(4)
C(11)	C(12)	C(13)	120.6(4)
C(8)	C(13)	C(12)	123.2(4)



Table VIII. Fractional Coordinates and Isotropic Thermal Parameters for the  
1,2-Mo<sub>2</sub>(o-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> Molecule.

Atom	x	y	z	B <sub>iso</sub>
Mo(1)	3160.7(2)	4722.8(2)	0.9(3)	11
N(2)	3723(2)	4629(2)	2261(3)	16
C(3)	4602(2)	4524(3)	2533(5)	22
C(4)	3478(2)	4572(3)	3796(5)	24
N(5)	3275(2)	3868(2)	-1384(4)	15
C(6)	4102(2)	3722(2)	-1596(5)	19
C(7)	2748(2)	3224(2)	-1987(5)	21
C(8)	3380(2)	5807(2)	-1032(4)	14
C(9)	3331(2)	5843(2)	-2714(5)	18
C(10)	3568(2)	6467(2)	-3484(5)	21
C(11)	3890(2)	7088(2)	-2576(5)	23
C(12)	3943(2)	7079(2)	-916(5)	22
C(13)	3692(2)	6461(2)	-131(4)	17
C(14)	3755(3)	6504(2)	1673(5)	22

Notes: (1) Fractional coordinates are  $\times 10^4$ . B<sub>iso</sub> values are  $\times 10$ .

(2) Isotropic values for those atoms refined anisotropically are calculated using the formula given by W.C. Hamilton, Acta Cryst. 1959, 12, 609.

Table IX. Bond Distances ( $\text{\AA}$ ) for the  $1,2\text{-Mo}_2(\text{o-tolyl})_2(\text{NMe}_2)_4$  Molecule.

A	B	Distance	A	B	Distance
Mo(1)	Mo(1)'	2.226(1)	C(8)	C(9)	1.407(5)
Mo(1)	N(2)	1.943(3)	C(8)	C(13)	1.418(5)
Mo(1)	N(5)	1.945(3)	C(9)	C(10)	1.382(5)
Mo(1)	C(8)	2.169(4)	C(10)	C(11)	1.380(6)
N(2)	C(3)	1.460(4)	C(11)	C(12)	1.385(6)
N(2)	C(4)	1.448(5)	C(12)	C(13)	1.391(5)
N(5)	C(6)	1.465(4)	C(13)	C(14)	1.507(5)
N(5)	C(7)	1.463(5)			

Table X. Bond Angles (deg) for the 1,2-Mo<sub>2</sub>(o-tolyl)<sub>2</sub>-(NMe<sub>2</sub>)<sub>4</sub> Molecule.

A	B	C	Angle
Mo(1)'	Mo(1)	N(2)	105.7(1)
Mo(1)'	Mo(1)	N(5)	103.4(1)
Mo(1)'	Mo(1)	C(8)	105.0(1)
N(2)	Mo(1)	N(5)	115.7(1)
N(2)	Mo(1)	C(8)	112.5(1)
N(5)	Mo(1)	C(8)	113.2(1)
Mo(1)	N(2)	C(3)	115.0(2)
Mo(1)	N(2)	C(4)	135.5(2)
C(3)	N(2)	C(4)	109.3(3)
Mo(1)	N(5)	C(6)	115.6(2)
Mo(1)	N(5)	C(7)	132.8(2)
C(5)	N(5)	C(7)	110.0(3)
Mo(1)	C(8)	C(9)	117.9(3)
Mo(1)	C(8)	C(13)	125.3(3)
C(9)	C(8)	C(13)	116.0(3)
C(8)	C(9)	C(10)	123.5(4)
C(9)	C(10)	C(11)	119.4(4)
C(10)	C(11)	C(12)	118.9(4)
C(11)	C(12)	C(13)	122.2(4)
C(8)	C(13)	C(12)	119.9(3)
C(8)	C(13)	C(14)	121.3(3)
C(12)	C(13)	C(14)	118.8(4)

### Captions to Figures

Figure 1. An ORTEP view of the 1,2-Mo<sub>2</sub>(benzyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule showing the atom number scheme.

Figure 2. Two stereoviews of the Mo<sub>2</sub>(benzyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> emphasizing the virtual, but not absolute, C<sub>2</sub> element of symmetry. The operation of a C<sub>2</sub> rotation about the virtual C<sub>2</sub> axis produces significant miss-match of the phenyl carbons, but has a minimal effect on the Mo<sub>2</sub>(C)<sub>2</sub>(NC<sub>2</sub>)<sub>4</sub> skeleton of the molecule.

Figure 3. An ORTEP view of the Mo<sub>2</sub>(benzyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule looking down the Mo-Mo bond.

Figure 4. An ORTEP view of the 1,2-Mo<sub>2</sub>(p-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule showing the atom number scheme.

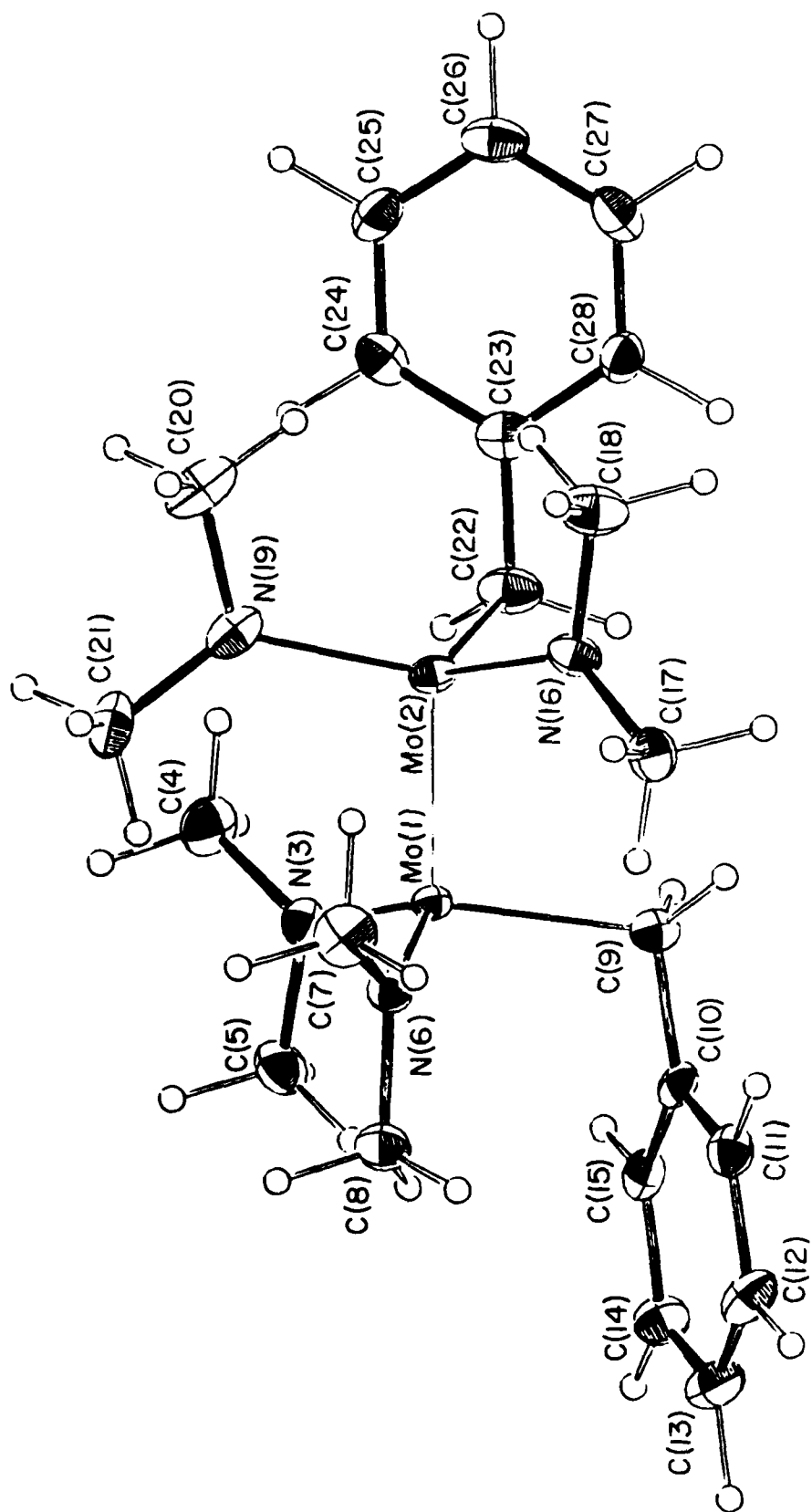
Figure 5. An ORTEP view of the 1,2-Mo<sub>2</sub>(p-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule viewed down the Mo-Mo bond.

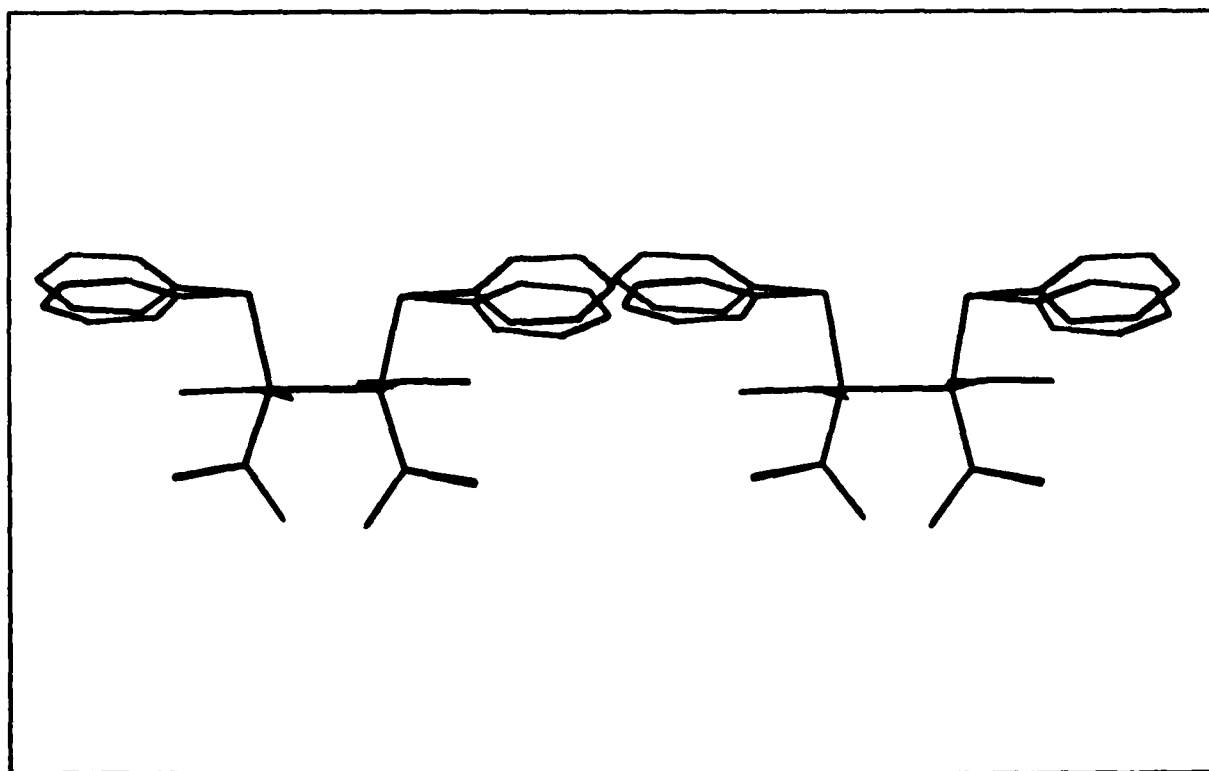
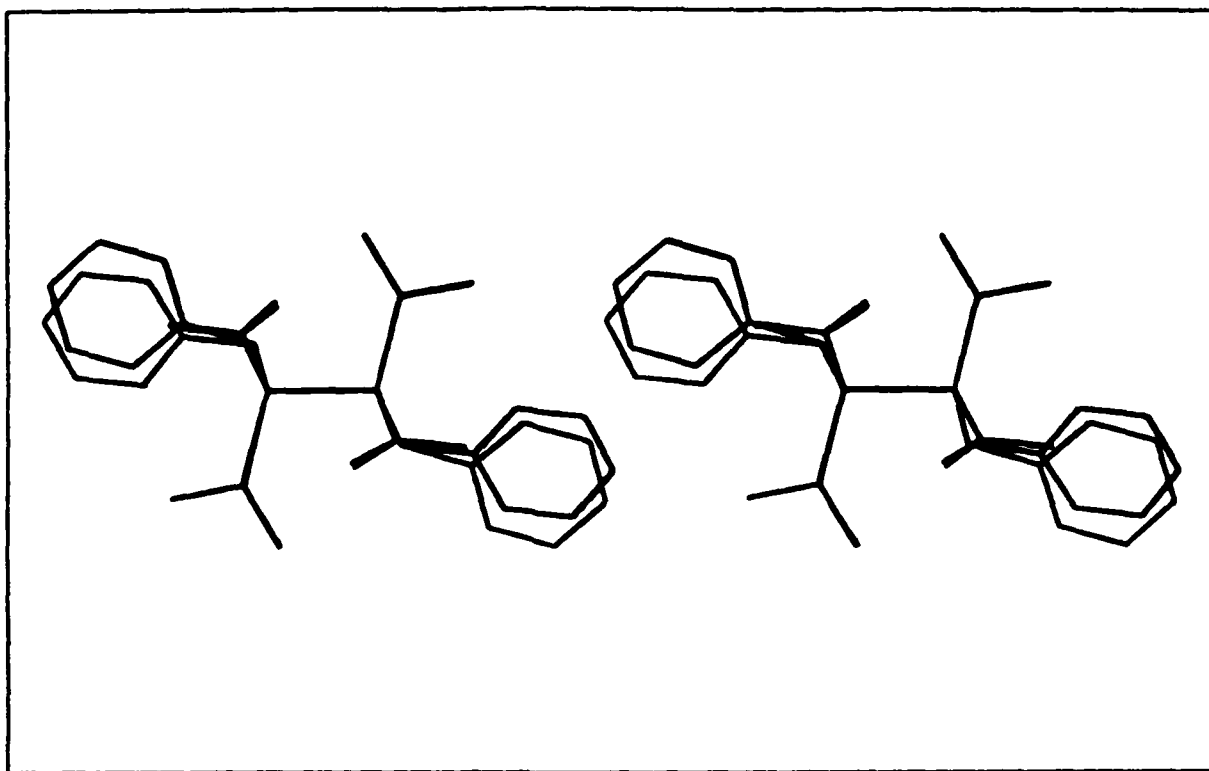
Figure 6. An ORTEP view of the 1,2-Mo<sub>2</sub>(o-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule viewed down the C<sub>2</sub> axis of symmetry and showing the atom number scheme used in the tables.

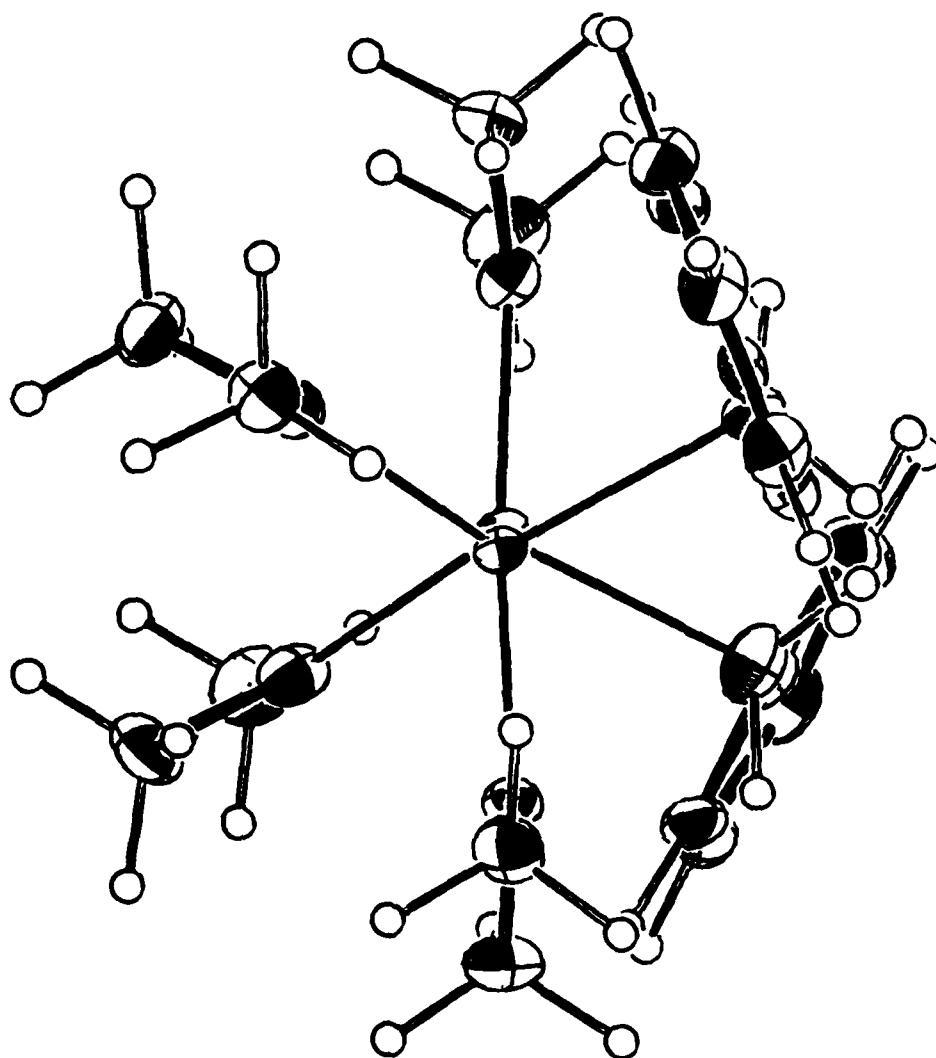
Figure 7. An ORTEP view of the 1,2-Mo<sub>2</sub>(o-tolyl)<sub>2</sub>(NMe<sub>2</sub>)<sub>4</sub> molecule looking down the Mo-Mo axis.

Figure 8. Low temperature limiting spectra of an equilibrium mixture of anti and gauche  $1,2\text{-Mo}_2(\text{p-tolyl})_2(\text{NMe}_2)_4$  recorded at  $-45^\circ\text{C}$  in toluene- $\text{d}_8$  at 220 MHz. Protio impurities in the toluene- $\text{d}_8$  give rise to signals denoted by an asterisk.

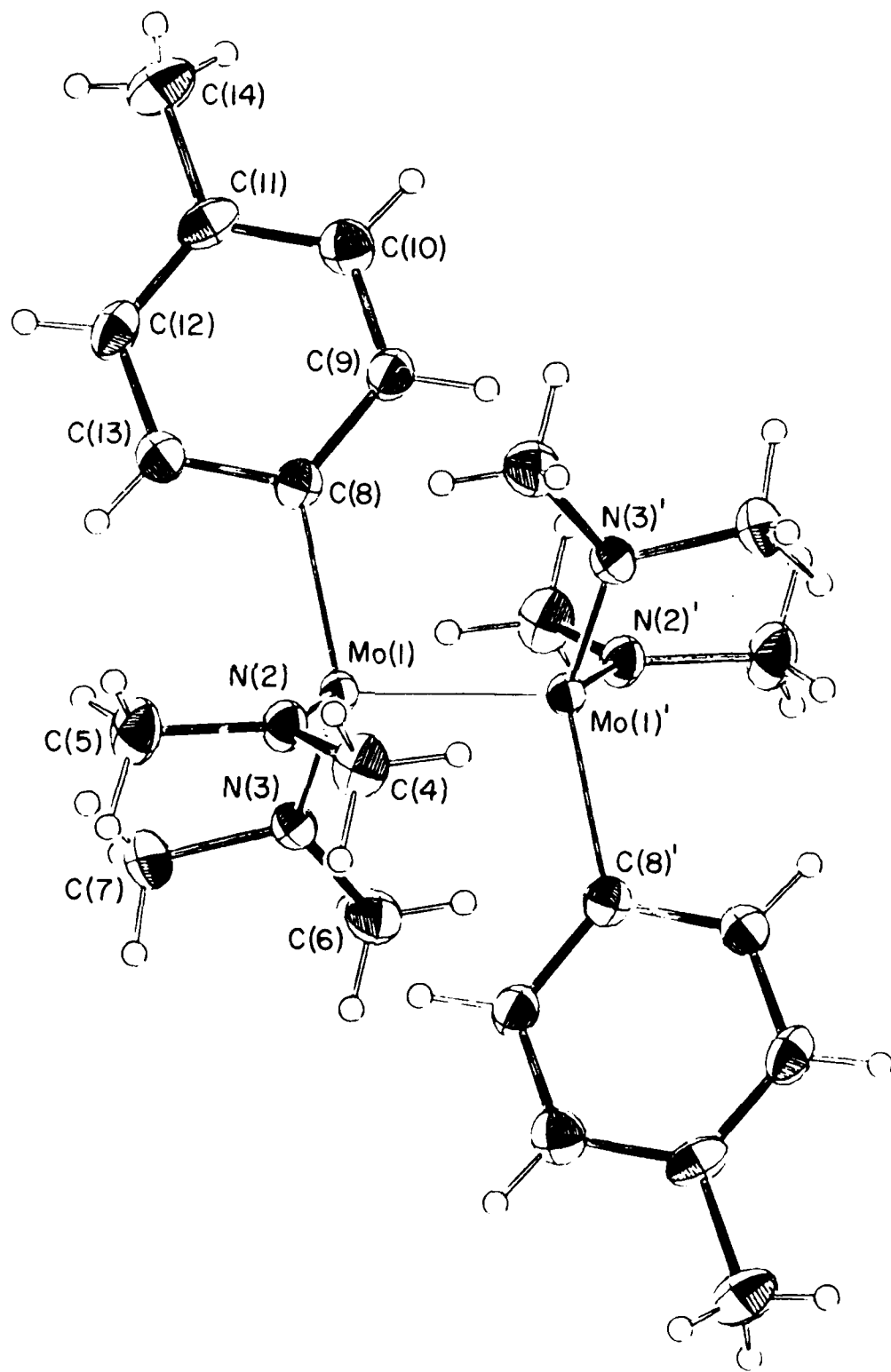
Figure 9.  $^1\text{H}$  nmr spectrum of gauche  $1,2\text{-Mo}_2(\text{o-tolyl})_2(\text{NMe}_2)_4$  recorded at  $-50^\circ\text{C}$ , 220 MHz in toluene- $\text{d}_8$  solvent. Signals arising from protio impurities in toluene- $\text{d}_8$  are denoted by an asterisk.

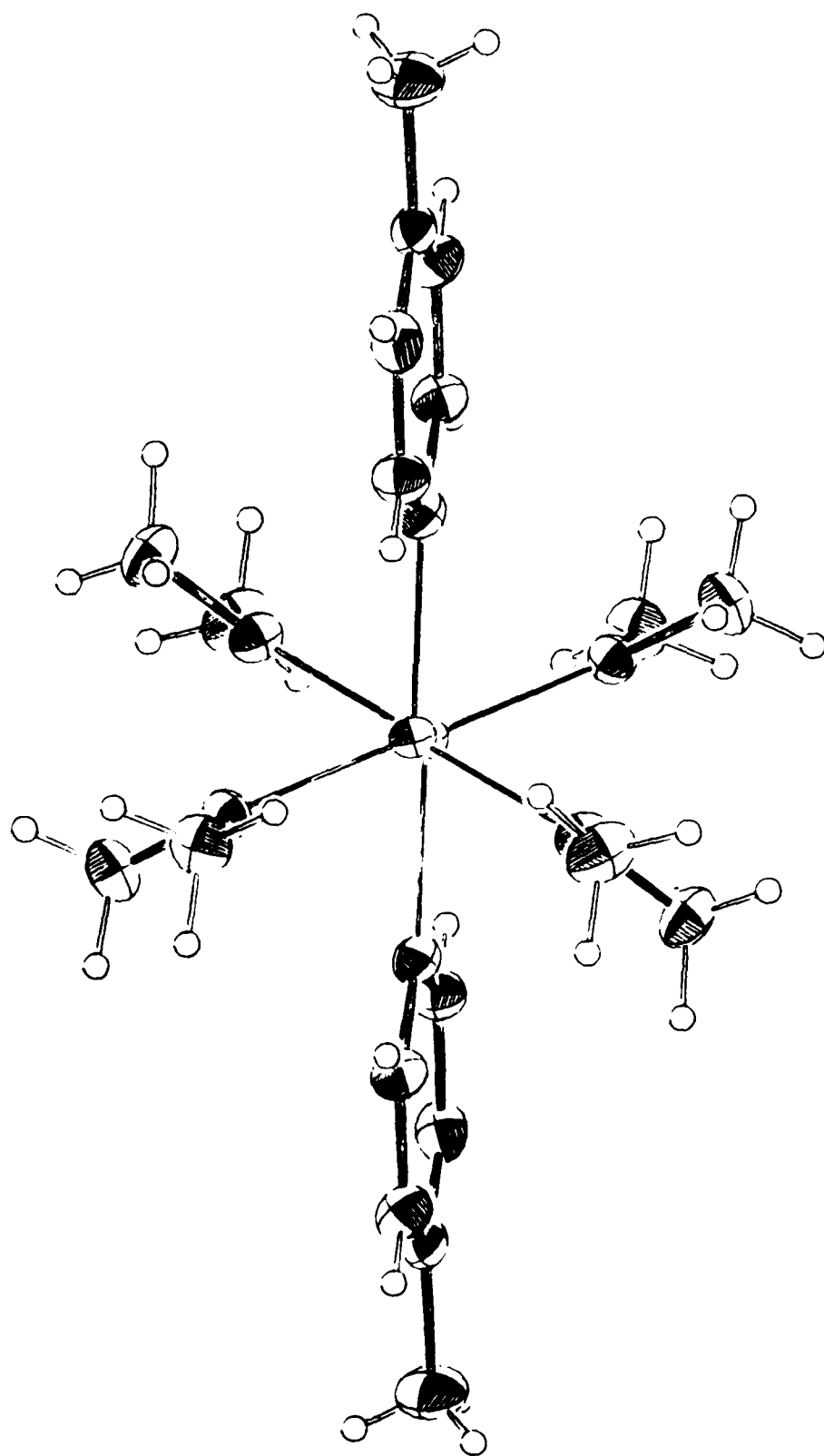


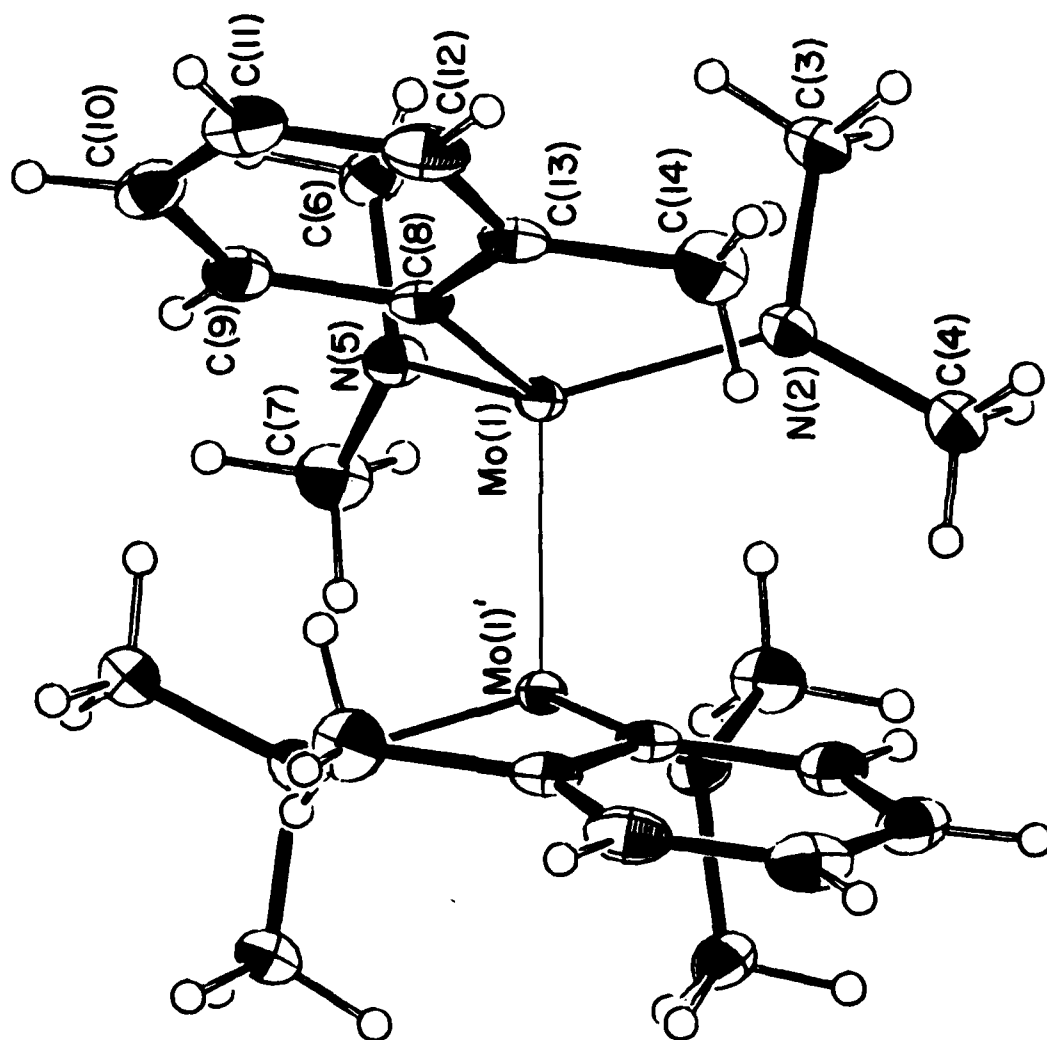


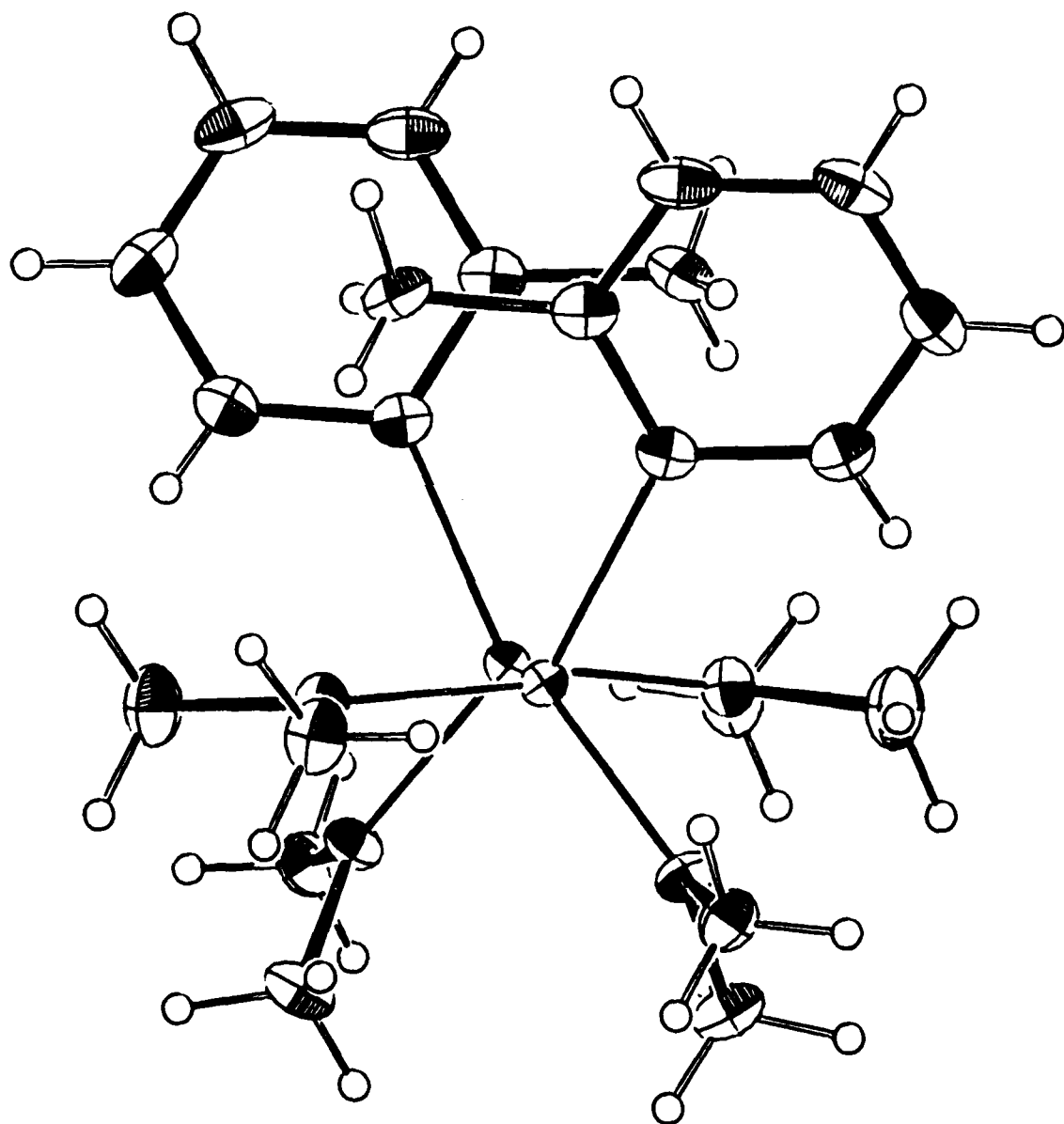




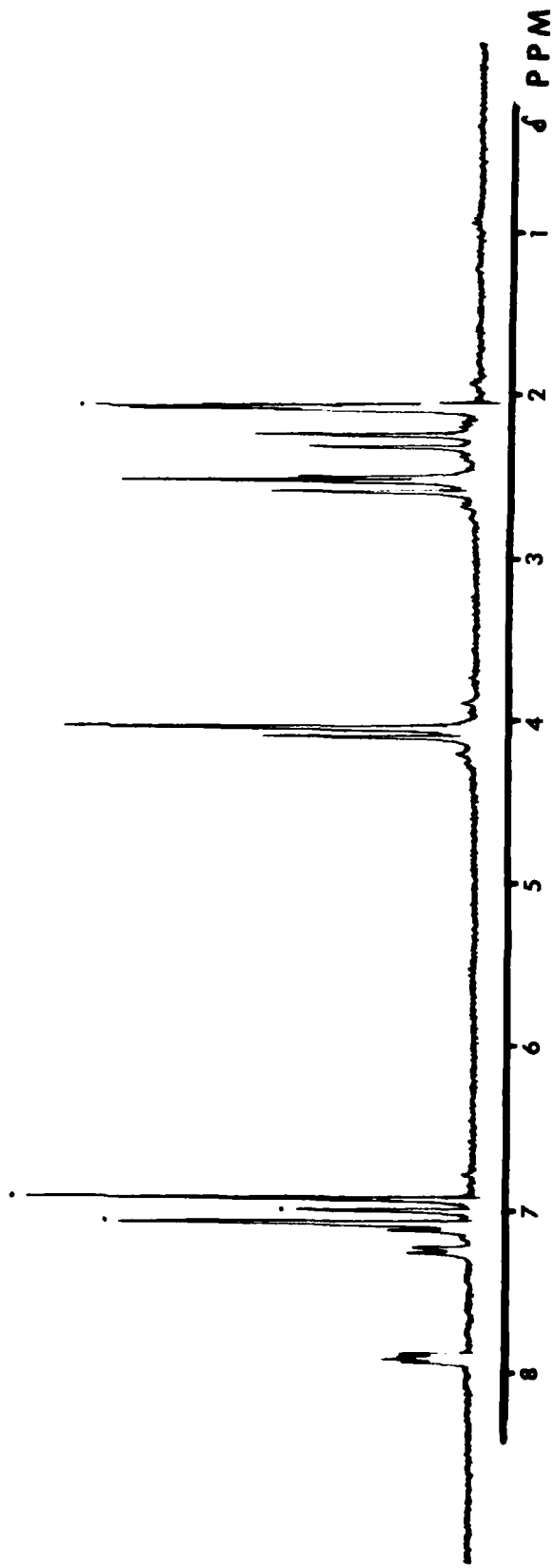




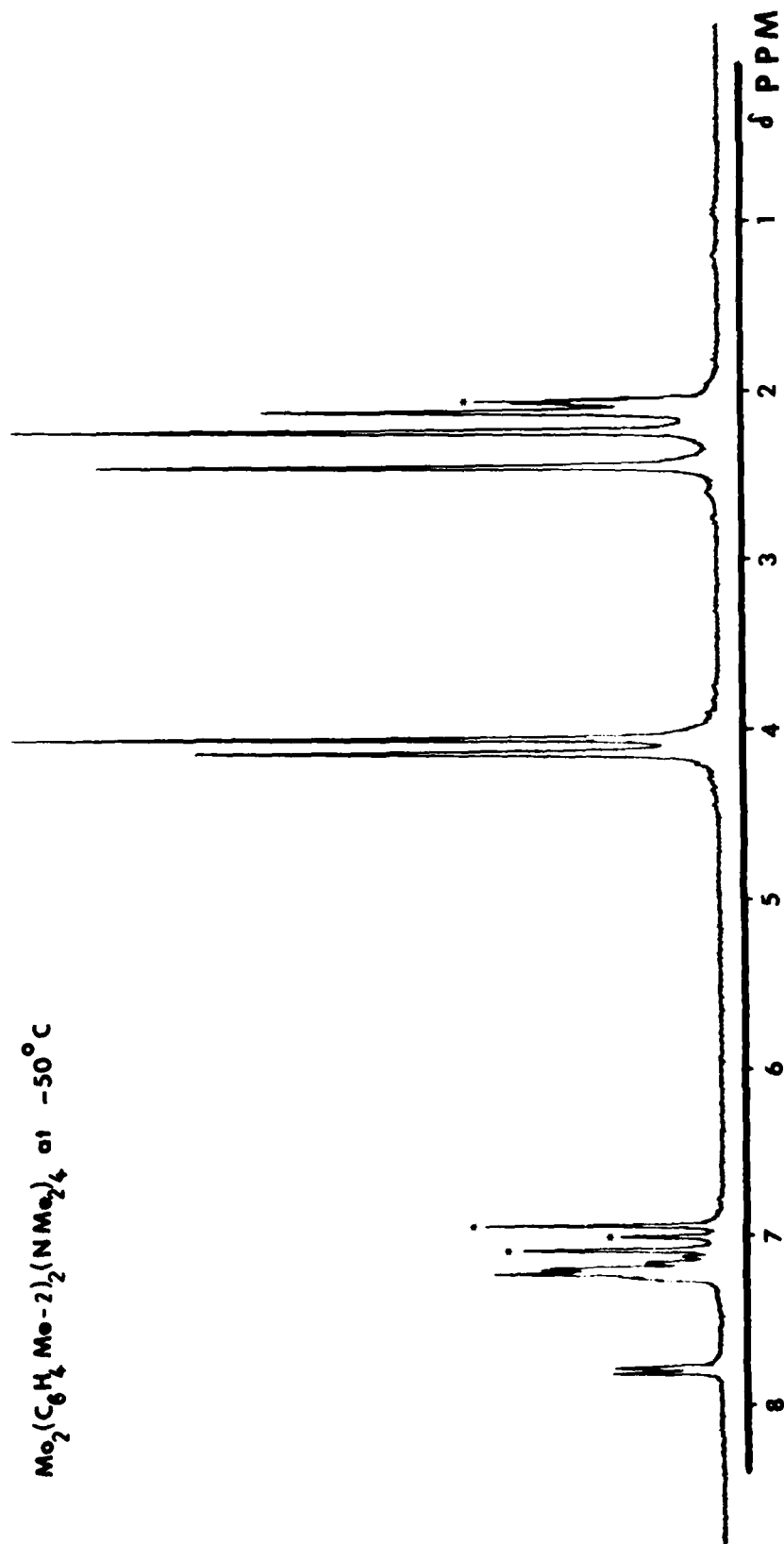




$^1\text{H}$  nmr spectrum of  
 $\text{Mo}_2(\text{C}_6\text{H}_4\text{Me}-4)_2(\text{NMe}_2)_4$   
at  $-45^\circ\text{C}$



$^1\text{H}$  nmr spectrum of  
 $\text{Mo}_2(\text{C}_6\text{H}_5\text{Me}-2)_2(\text{NMe}_2)_4$  at  $-50^\circ\text{C}$



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